DIEL VERTICAL MIGRATION SUSPECTED IN SOME COPEPODS AND CHAETOGNATHS IN THE INLET WATERS, WITH A SPECIAL REFERENCE TO BEHAVIOURAL DIFFERENCES BETWEEN MALE AND FEMALE, NOTED IN THE FORMER

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With Text-figures 1–11

Introduction

The diel vertical migration has been reported generally on many plankton animals in the open sea, but much less frequently on those in the inlet-waters. In chaetognaths in the Japanese inlet-waters, solely sinking down of *Sagitta crassa* f. *naikaiensis* in the daytime was referred to by Murakami (1959), and in copepods in the inlet-waters more frequent and abundant occurrences of *Labidocera* at night was ever noted by Wada (1953). Recently Motoda *et al.* (1971) reported that the copepod, *Acartia clausi*, appeared in Oshoro Bay, Hokkaido densely in the surface water immediately after sunset, with the maximum around midnight and then gradually decreasing to the extremely lower density in the daytime. Further, Anraku (1975) noted that the major part of *A. clausi* population in the same bay was restricted close to the bottom even at twilight and the whole population was found in the daytime aggregated more closely to the bottom than at twilight.

It is clear that the distribution of plankton animals, even in the inlet-waters, cannot be explained satisfactorily unless the pattern of their diel vertical migration is fully understood. Thus, during the plankton survey of Maizuru Bay, special efforts were made to explain the diel change observed in the animal plankton in the bay water. Then, 54 collections of plankton were made successively at two stations in the bay in April and October 1974. On the results of analyses of this material, the diel change of the vertical distribution was checked in two chaetognaths, *Sagitta enflata* and *S. crassa* f. *naikaiensis*, and three copepods, *Acartia clausi*, *Paracalanus* sp. and *Oithona nana*. Further, it was alluded that the pattern of the diel vertical migration was somewhat different between male and female in copepods, especially markedly in *Acartia clausi*. The difference between male and female is known in the vertical migration with age in some open-sea copepods, for instance *Calanus finmarchicus* and especially referred to briefly by Motoda and Sato (1949) as to the diurnal migration of *Clausocalanus*, *Pseudocalanus*, *Tortanus* and *Centropages* in the open sea area off Shiretoko, Hokkaido, but seemingly this has not been yet reported so far in

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the diel verical migration of inlet-water copepods. Therefore, this paper is presented mainly to offer the data suggesting the above-mentioned difference.

Before going further, the author wishes to express his hearty thanks to Prof. T. Tokioka of the Seto Marine Biological Laboratory for his helpful advices and kindness in reading the manuscript, and also to Mr. Hideo Akamatsu and his members of the oceanographical section of the Maizuru Marine Observatory for their kindness in generously giving the author the chance to carry out the present study and in helping him in collecting samples.

Material and method

The 54 plankton samples were collected at Stations A and B in the inner part of Maizuru Bay on the Japan Sea coast (Fig. 1).

In April, 1974 an ocean data buoy was fixed at Station B, 9 m deep, and mete-

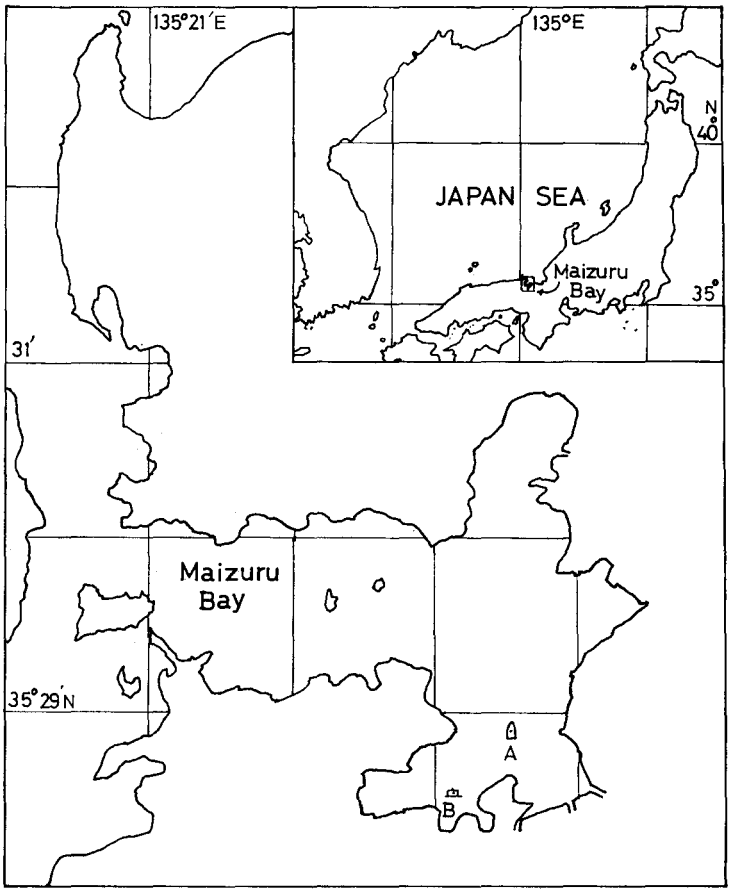

Fig. 1. Map showing the position of two stations. B: Buoy anchored, observations and collections were made from 23rd to 24th in April, 1974. A: R.V. Seifu Maru anchored, observations and collections were made from 15th to 16th in October, 1974.

orological and oceanographical observations were made on it from 9:00 h on 23rd to 12:00 h on 24th. Together with these observations water samples were taken from the layers of 0, 2 and 7 m, and at the same time 24 vertical hauls were made from 7 m to the surface using a Kitahara's quantitative net with a 30 cm mouth diameter and stretched with the fine bolting silk XX-13.

In October, 1974, when the R.V. Seifu Maru, 355 tons, of the Maizuru Marine Observatory anchored at Station A, 9 m deep, oceanographical observations were made every other hour from 12:30 h on 15th to 16:30 on 16th. Water samples were collected in the layers of 0, 2, 5 and 7 m, and 15 vertical hauls, respectively from 2 and 7 m to the surface, were made with the same net during this period.

Diel changes of the occurrence of two dominant copepods, *Paracalanus* sp. and *Oithona nana*, were checked in both sexes and copepodite. The same check was made in two chaetognaths in their four developmental stages. And the vertical migration in these animals and differences in its pattern between male and female were suspected on the results of these examinations.

Diel changes in the vertical distribution of animal plankton in April, 1974

As the meteorological and hydrographical conditions observed at Station B are

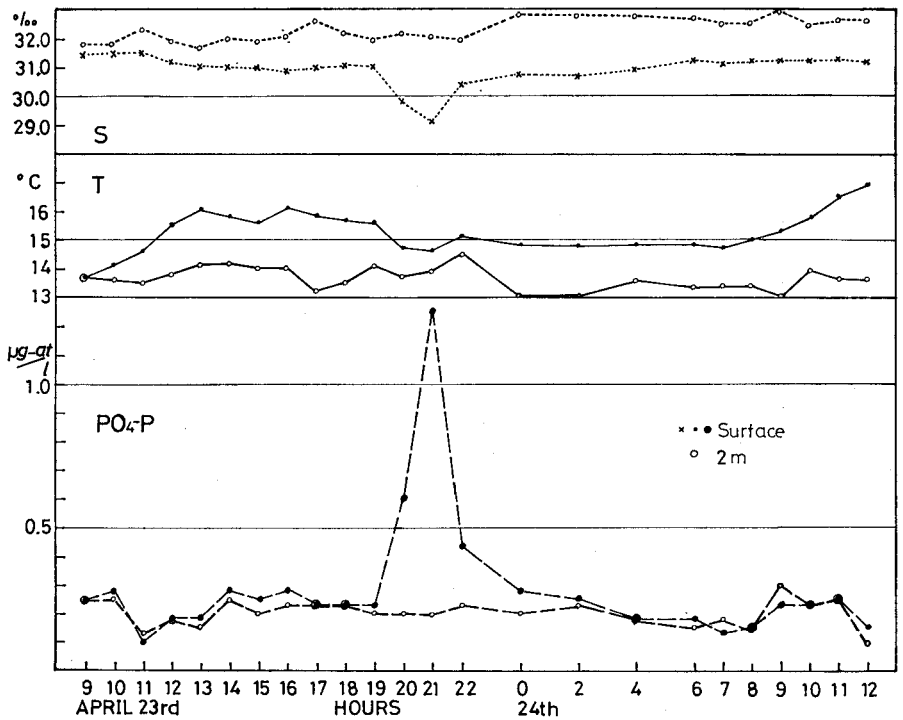

Fig. 2. Diel changes of salinity (S), water temperature (T) and phosphate phosphorus (PO_4-P—in μg-at/l) in surface and 2m layers at Station B.

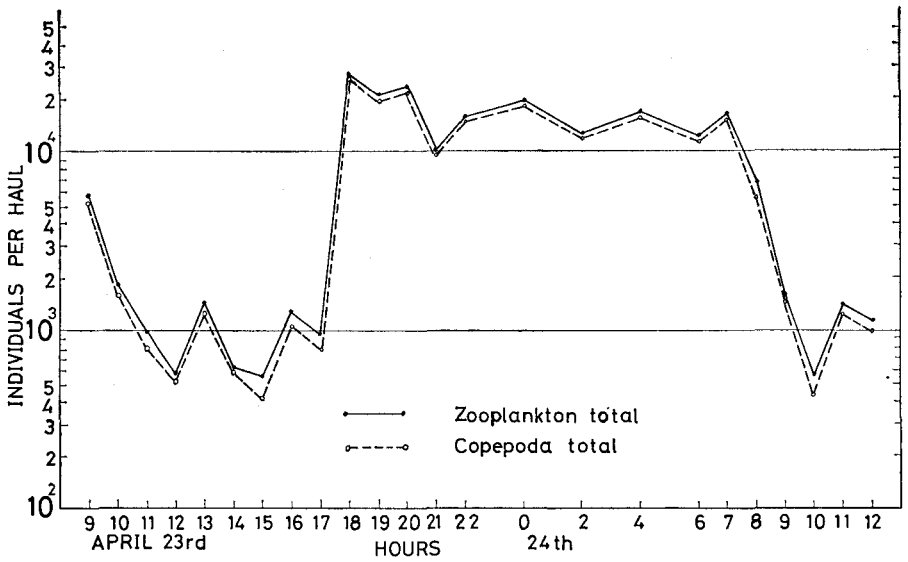

Fig. 3. Diel changes of the amount of total animal plankton and total copepods at Station B, shown by individuals per haul.

reported in detail by Kitou and Eguchi (1975), only the three elements of the data at the surface and 2 m layers are reproduced in Figure 2 in this paper. There, it is shown clearly that the water temperature and salinity were lowered and phosphate phosphorus was increased suddenly in the surface layer at the lowest water at 21:00 h on 23rd, while no evident changes were seen in the 2 m layer.

Diel changes of the occurrence of total animal plankton are shown in Figure 3, together with those of total copepods. The figure shows only that the amount of total animal plankton and total copepods was much smaller in the daytime than at night as reported already by many workers.

Of copepods, *Acartia clausi* was very predominant in the samples, occupying 46–95 % of total animal plankton (Table 1). Motoda and Sato (1949) pointed out that the diurnal migration of some copepods was different between female and male. Björnberg and Wilbur (1968) reported experimentally that the diurnal migratory cycle of *Acartia* was different between adults and younger forms in copepodite stages. Therefore, the author checked the number of *A. clausi* separately in adult female, adult male, and copepodites. The results are shown in Figure 4 and Table 1. It is evident that males were much fewer in the daytime, especially at noon on 23rd they were completely absent in the sample hauled above 7 m. On the other hand, females maintained the amount in the range from 250 at 15:00 h to 980 individuals at 13:00 h per haul during the time from 10:00 to 17:00 h on 23rd. After sunset, males increased the amount suddenly from 140 (at 17:00 h) to 12,200 individuals per haul (at 18:00), about one hundred times as large as the former. They decreased gradually towards the dawn, to 4,900 individuals per haul at 7:00 h on 24th, but after sunrise the amount dropped again rapidly.

Table 1. Diel changes of the amount of animal plankton, especially of copepods, collected from 7 m to the surface at Station B in Maizuru Bay from 9:00 h on 23rd to 12:00 h on 24th of April, 1974.

Time	09	10	11	12	13	14	15	16	17	18	19	20
(inds./haul) Zooplankton total	5,660	1,780	975	570	1,410	615	550	1,250	950	27,200	20,400	22,500
Copepoda total	5,160	1,580	795	510	1,240	600	420	1,060	790	25,500	19,200	22,000
Acartia clausi ♀	1,500	580	435	450	980	510	250	810	460	6,000	6,100	6,100
" " ♂	1,780	280	165	—	180	15	40	160	140	12,200	7,700	9,400
" " copepodites	100	80	45	15	50	—	—	—	—	—	100	400
Copepoda miscs.	1,780	640	150	45	30	75	130	90	190	7,300	5,300	6,100
Zooplankton miscs.	500	200	180	60	170	15	130	190	160	1,700	1,200	500

Time	21	22	00	02	04	06	07	08	09	10	11	12
(inds./haul) Zooplankton total	10,000	15,600	19,300	12,600	16,600	12,000	16,200	6,700	1,545	570	1,380	1,110
Copepoda total	9,600	15,100	18,200	11,950	15,800	11,400	15,200	5,600	1,470	435	1,215	1,000
Acartia clausi ♀	4,400	5,200	5,200	3,350	5,500	2,500	4,200	1,300	1,065	330	1,065	880
" " ♂	2,700	5,800	10,200	5,300	5,100	2,800	4,900	1,700	210	30	30	50
" " copepodites	500	200	300	350	500	600	400	100	30	30	15	20
Copepoda miscs.	2,000	3,900	2,500	2,950	4,700	5,500	5,700	2,500	165	45	105	50
Zooplankton miscs.	400	500	1,100	650	800	600	1,000	1,100	75	135	165	110

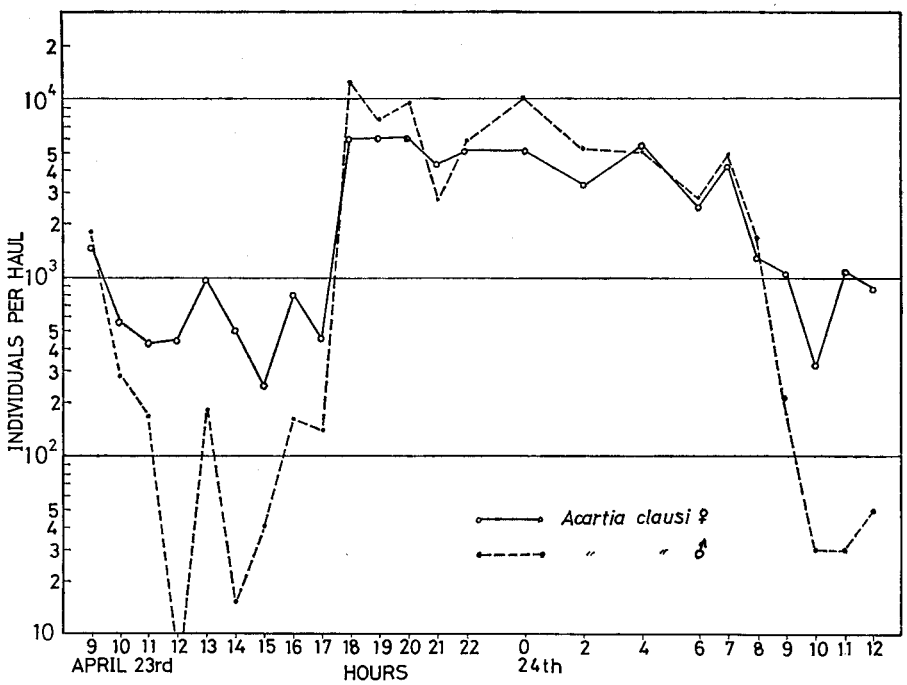

Fig. 4. Diel changes of the occurrence of *Acartia clausi* at Station B, given by individuals per haul in adult female and male.

Females also increased after sunset, but the amount at night was about ten times that in the daytime, fluctuating between 2,500 and 6,100 individuals per haul in the period from sunset to the dawn; the amount decreased again after sunrise.

It is noteworthy that numbers of females and males well conform to each other in the time from 4:00 to 8:00 h on 24th; this might be related to the reproductive behaviour of this copepod, as Yamada (1958) suggested that *Engraulis japonicus* should shoot spawn in the time from midnight to 4:00 h in Omura Bay, Kyushu Island and Sakano (1968) also reported that the same fish should release eggs before midnight in Wakasa Bay on the Japan Sea coast. The period around midnight seemingly might have some ecological effect on animal plankton.

Younger forms in copepodite stages were much fewer as far as the present observations are concerned, particularly in the daytime they often disappeared wholly in samples.

Diel changes in the vertical distribution of copepods in October, 1974

Hydrographical conditions at Station A in October were already reported by the oceanographical section of the Maizuru Marine Observatory (1974), therefore only four elements of them at the surface and 7 m layers are given again in Figure 5 in this paper. As in April, the water temperature and salinity decreased and phos-

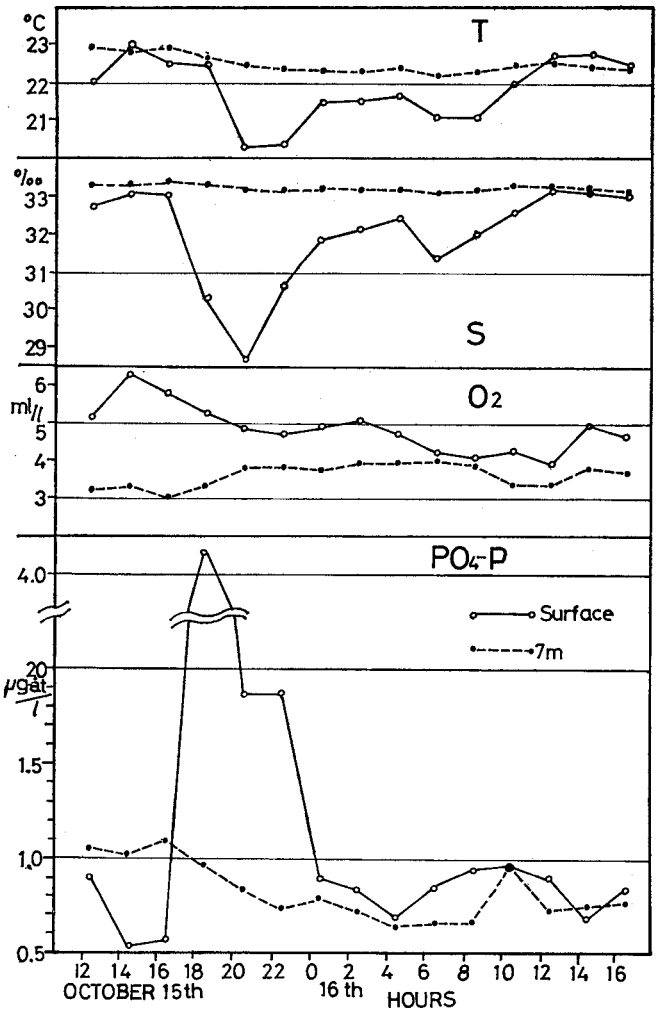

Fig. 5. Diel changes of water temperature, salinity, dissolved oxygen (ml/*l*) and phosphate phosphorus (PO_4-P in μg-at/*l*) at Station A.

phate phosphorus increased at the surface at the lowest water at 20:30 h on 15th, but no significant changes were observed in the 7 m layer.

The most dominant species of copepods were *Paracalanus* sp. and *Oithona nana* in this season. *Paracalanus* sp. in the present material from Maizuru Bay was closely related to *Paracalanus parvus*, but much smaller than the latter, only 0.5 mm in female and 0.4 mm in male. This might represent only a minor inlet-water form of *P. parvus*, but in this paper it is recorded separately from *parvus*. Diel changes of the occurrence of these two copepods are given in Figure 6 and Table 2 as individuals per haul from 7 m to the surface, separately in adult female, adult male and younger forms in copepodite stages. Females predominated males in both species in every sample.

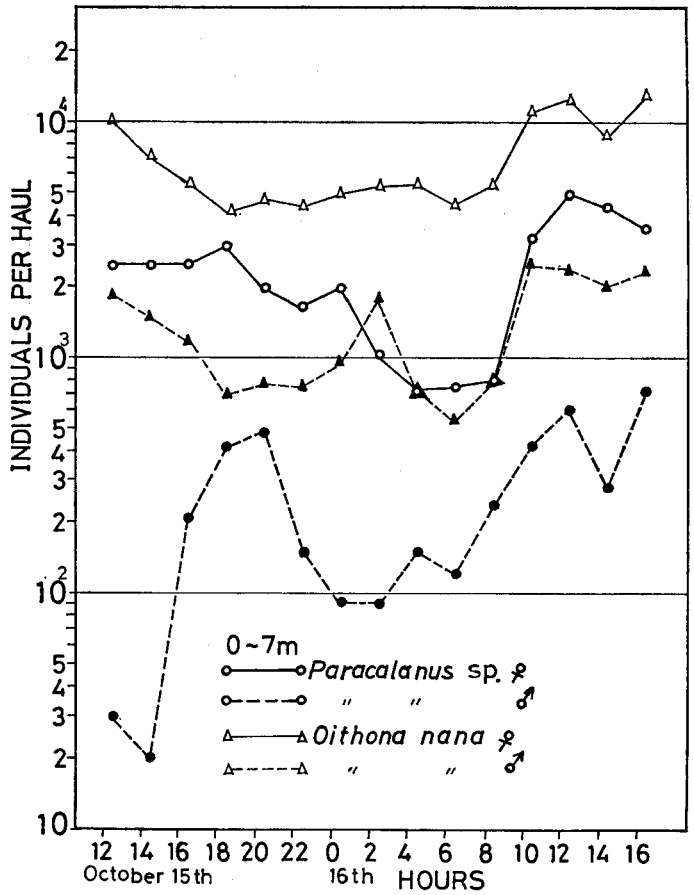

Fig. 6. Diel changes of the occurrence of *Paracalanus* sp. and *Oithona nana*, given separately in adult female and male at Station A, numbers in individuals per haul.

Numbers of dominant copepods in the 2–7 m layer were calculated by treating 7 m–0 and 2 m–0 hauls in a step method and these are shown in Figures 7 and 8 as individuals per cubic meter, together with the numbers in the 0–2 m layer.

Diel changes of the occurrence of *Paracalanus* sp. at this station given in Figure 7 show that females predominated males in both layers. Females were denser in the 2–7 m layer than in the 0–2 m layer during the period from 12:30 h on 15th to 0:30 on 16th, but the density became almost the same in two layers in the time from midnight to early morning. Males were similarly denser in the 2–7 m layer than in the 0–2 m layer during the period from 14:30 h to midnight on 15th, but the density was *vice versa* from midnight to early morning. In both sexes, the vertical distribution looked irregular in the afternoon on 16th. Probably this is reflecting the inflow of the oceanic water deep into the bay, that was suspected by higher water temperature and salinity at the station after 12:30 h on 16th as seen in Figure 5.

Diel changes of the occurrence of *Oithona nana* given in Figure 8 show that fe-

Table 2. Diel changes of the amount of copepods and chaetognaths collected from 7 m to the surface at Station A in Maizuru Bay from 12:30 on 15th to 16:30 on 16th of October, 1974.

Time	12 : 30	14 : 30	16 : 30	18 : 30	20 : 30	22 : 30	00 : 30	02 : 30	04 : 30	06 : 30	08 : 30	10 : 30	12 : 30	14 : 30	16 : 30
(inds./haul)															
Paracal. sp. ♀	2,460	2,480	2,490	2,970	1,980	1,620	1,950	1,020	750	750	810	3,150	4,890	4,280	3,480
" " ♂	30	20	210	420	480	150	90	90	150	120	240	420	600	280	720
Oithona nana ♀	10,110	7,140	5,580	4,200	4,700	4,410	4,980	5,220	5,380	4,410	5,400	10,920	12,440	8,560	12,760
" " ♂	1,800	1,470	1,170	690	780	750	930	1,770	720	540	780	2,460	2,320	2,000	2,320
" copepodites	3,600	1,680	2,070	1,710	1,580	870	1,290	810	3,000	1,410	2,010	3,520	3,960	1,940	1,400
Cope. nauplii	4,230	4,840	6,750	8,460	3,990	2,910	4,890	2,970	2,610	3,480	4,620	8,490	10,440	7,120	5,640
Sag. crassa I	46	167	88	60	97	56	48	72	84	68	121	153	220	109	137
" " II	3	10	3	8	1	3	2	3	4	4	3	3	2	2	1
" " III	—	2	2	1	2	3	3	4	4	—	1	—	—	1	1
" " IV	—	—	—	—	1	2	1	—	—	—	—	—	—	—	—
S. enflata I	1	2	1	4	2	—	1	1	1	—	—	1	1	—	3
" " II	—	—	—	—	—	—	—	1	1	1	—	1	—	1	2
" " III	—	—	—	—	—	—	—	1	1	1	—	—	—	1	1
" " IV	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—

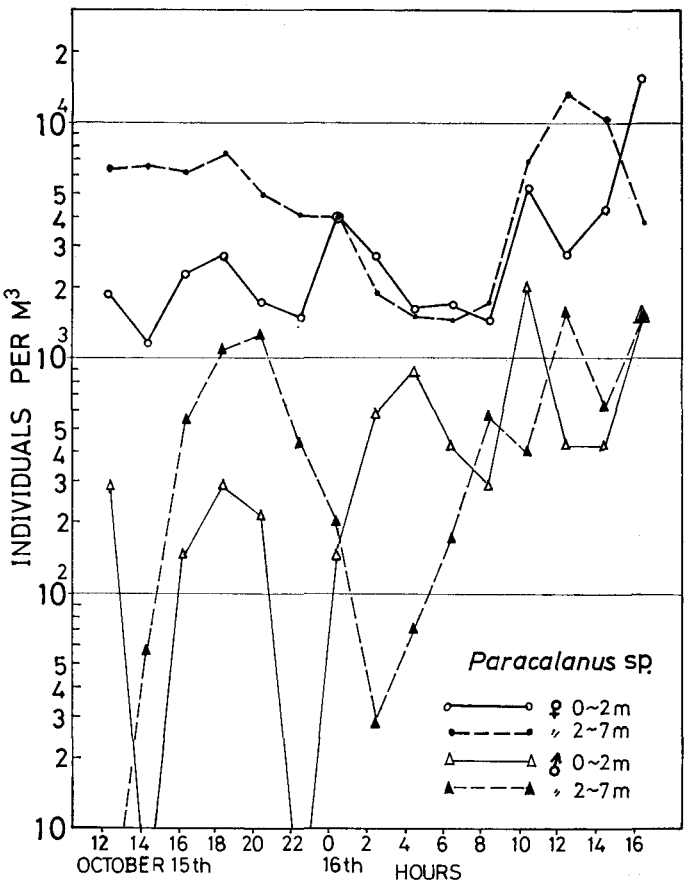

Fig. 7. Diel changes of the occurrence of *Paracalanus* sp. given separately in adult female and male in 0–2 m and 2–7 m layers at Station A. Numbers in individuals per cubic meter.

males were distributed rather irregularly in the time from noon to midnight on 15th, ranging from 3.5×10^3 to 27×10^3 individuals per cubic meter in the 0–2 m and from 9.6×10^3 to 18×10^3 in the 2–7 m layer, though they were denser in the 0–2 m layer than in the 2–7 m layer during the period from midnight to early morning, reaching to 38×10^3 individuals per cubic meter in the 0–2 m layer at 4:30 h on 16th, when they completely disappeared suddenly in the 2–7 m layer. Males were denser in the 2–7 m layer than in the 0–2 m layer during the period from noon to midnight on 15th, but then became denser in the 0–2 m layer than in the 2–7 m layer, especially it was notable that males were wholly absent in the 2–7 m layer at 6:30 h on 16th. After sunrise, males increased abruptly in the 2–7 m layer and became denser in the daytime than in the 0–2 m layer.

Comparing the vertical distribution of *Oithona nana* with that of *Acartia clausi*, it is noted that the abrupt change appeared after midnight in the former, while after sunset in the latter.

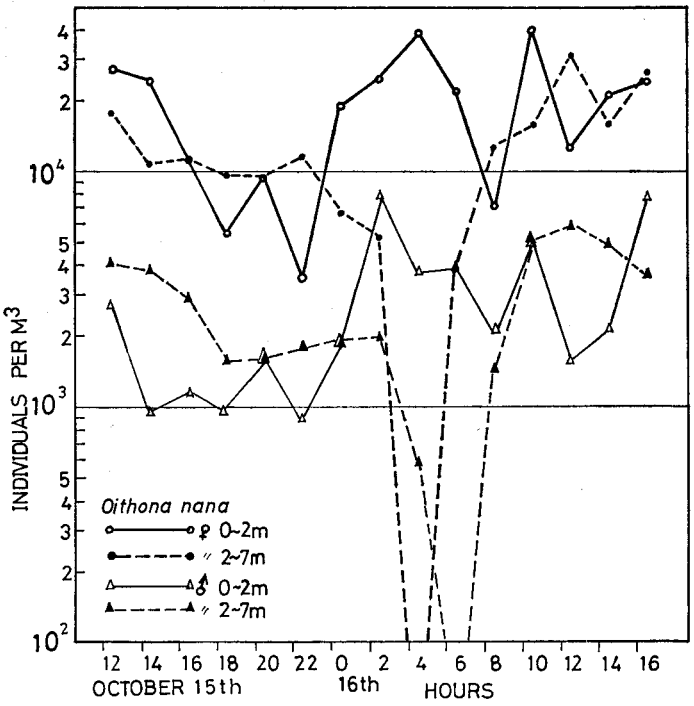

Fig. 8. Diel changes of the occurrence of *Oithona nana*, given separately in adult female and male in 0–2 m and 2–7 m layers at Station A. Numbers in individuals per cubic meter.

Larval forms such as nauplii of barnacles and copepods seemed generally living in the surface layer. Diel changes of the occurrence of copepod nauplii given in Figure 9 show that their occurrence was rather stable in the 0–2 m layer and fluctuated in the range from 2.5×10^3 to 8.4×10^3 individuals per haul (Table 3), while it was quite irregular in the 2–7 m layer, 90 to 3×10^3 individuals per haul in some samples or wholly absent in others.

Diel changes in the vertical distribution of chaetognaths in October, 1974

The number of chaetognaths was checked separately in the following four stages of maturation.

Stage I. Ovaries and seminal vesicles undefinable.
Stage II. Ovaries and seminal vesicles definable.
Stage III. Ovaries and seminal vesicles fully developed.
Stage IV. Seminal vesicles ruptured.

The dominant species was *Sagitta crassa* f. *naikaiensis*, but even in this species matured individuals were so few that respective samples were examined thoroughly

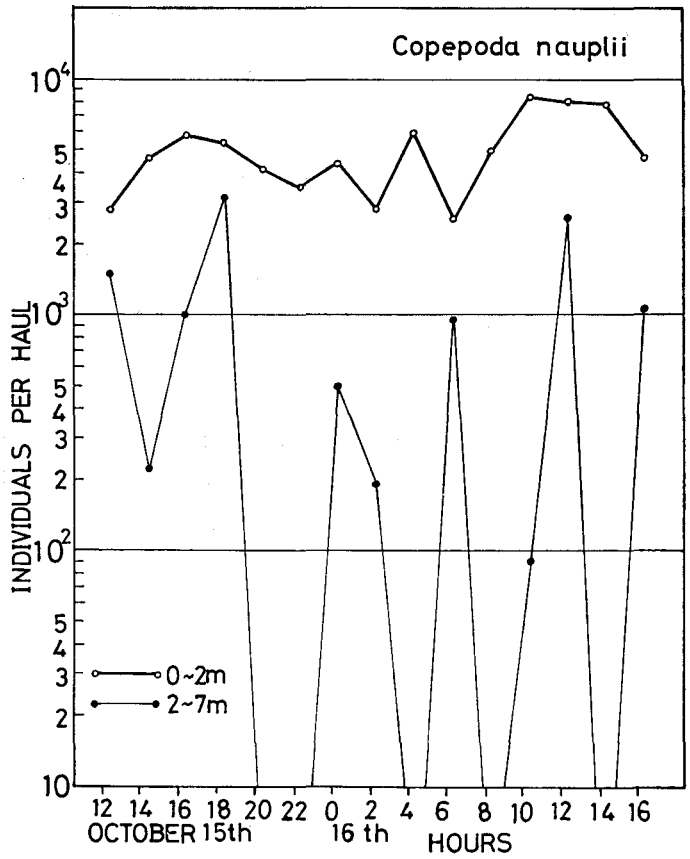

Fig. 9. Diel changes of the occurrence of copepod nauplii in 0–2 m and 2–7 m layers at Station A. Numbers in individuals per haul.

at counting.

Diel changes of the occurrence of this chaetognath is shown in Figure 10. The individuals in the 2–7 m layer were calculated as in the case of copepods. Young specimens of the Stage I fluctuated in the range from 2 to 82 individuals per haul in the 0–2 m layer, but 0 to 200 in the 2–7 m layer; strangely no young specimens were seen in the 2–7 m layer at noon on 15th and only a few individuals in the 0–2 m layer around midnight.

Specimens of the Stages II and III appeared nearly in every sample, though absent in samples from the 0–2 m layer in the daytime on 16th; this might be related to the inflow of the oceanic water into the surface layer at this station. Specimens of the Stage IV were represented in only three samples collected at night by a single individual, at 20:30 and 22:30 on 15th in the 2–7 m layer and 22:30 to midnight in the 0–2 m layer respectively.

Small numbers of an oceanic chaetognath, *Sagitta enflata*, were found, too and its occurrences are shown in Figure 11. No specimen was found in the 0–2 m layer during the period from noon to midnight on 15th, when only young specimens of the

Table 3. Diel changes of the amount of copepods and chaetognaths collected from 2 m to the surface at Station A in Maizuru Bay from 12:30 on 15th to 16:30 on 16th of October, 1974.

Time	12 : 30	14 : 30	16 : 30	18 : 30	20 : 30	22 : 30	00 : 30	02 : 30	04 : 30	06 : 30	08 : 30	10 : 30	12 : 30	14 : 30	16 : 30
(inds./haul)															
Paracal. sp. ♀	260	160	320	380	240	200	560	380	225	240	200	740	390	600	2,160
" " ♂	40	—	20	40	30	—	20	80	125	60	40	280	60	60	210
Oithona nana ♂	3,780	3,420	1,600	78	1,320	500	2,660	3,400	5,380	3,040	1,000	5,460	1,740	2,960	3,340
" " ♂	380	140	160	140	220	120	260	1,080	520	540	280	680	220	300	1,060
" copepodites	1,920	1,080	940	640	720	320	580	300	3,000	1,000	1,060	3,520	1,420	1,940	1,200
Cope. nauplii	2,760	4,620	5,740	5,420	4,080	3,440	4,400	2,780	5,850	2,540	4,920	8,400	7,860	7,920	4,620
Sag. crassa I	78	59	36	12	12	2	3	38	44	40	82	48	21	36	67
" " II	2	4	1	2	1	—	1	3	4	2	1	—	—	—	—
" " III	2	1	—	1	1	—	1	4	3	—	—	—	—	—	—
" " IV	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—
Sag. enflata I	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
" " II	—	—	—	—	—	—	1	—	—	—	—	1	—	1	—
" " III	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—
" " IV	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

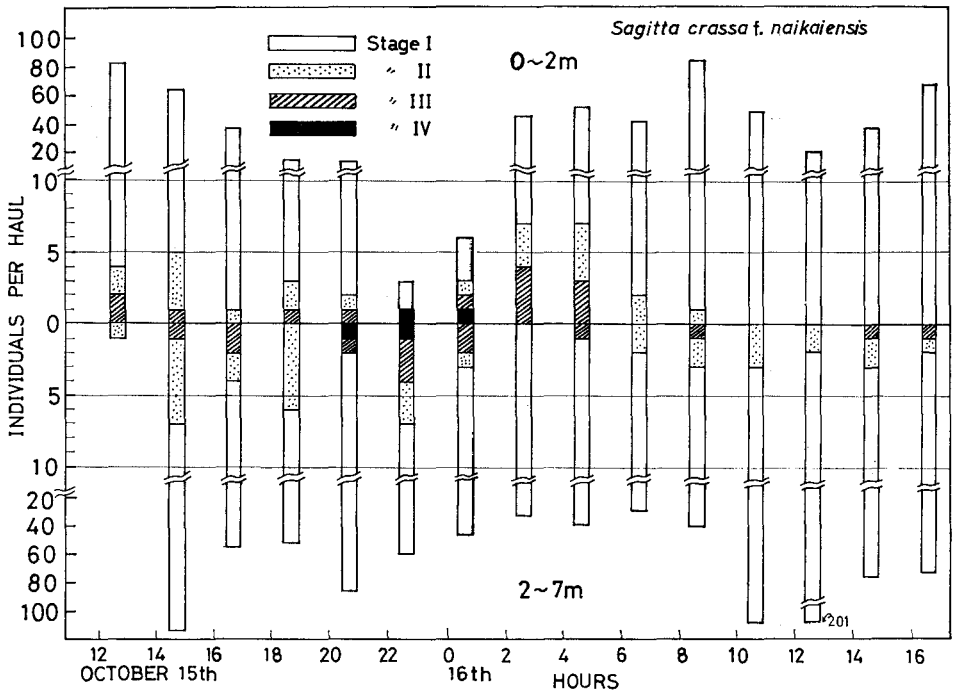

Fig. 10. Diel variations of the occurrence of *Sagitta crassa* f. *naikaiensis*, given separately in four maturation stages I to IV in 0–2 m (above) and 2–7 m (below) layers at Station A. Numbers in individuals per haul.

Stage I occurred in the 2–7 m layer. In the time from midnight to the dawn on 16th, only single specimens of the Stages II and III were found in the two layers, the specimen of the Stage IV was represented in the 2–7 m layer by only a single individual once at 2:30 h on 16th. Occurrences of a few specimens in the two layers in the daytime on 16th were quite irregular. Throughout the occurrences of two chaetognaths in the bay, the global solar radiation (Fig. 11, below) was seemingly unrelated with the vertical distribution of the two chaetognaths at this station in this season. Yamada (1958) stated that *Sagitta enflata* occurred only in a small number in the daytime, but increased at night in the surface layer in Omura Bay, Kyushu Island. Although the observed specimens were very few in the present material, it is likely that adult *enflata* appears around midnight in Maizuru Bay, too. This pattern of vertical distribution might be related not only to the light intensity, but also correlated with the reproduction behaviour.

Considerations

As the results of examinations on chaetognaths given here do not seem large enough to show any definite behavioural trends, the author wants to leave the data to those who can avail them for further studies. On the other hand, the data about three copepods, especially *Acartia clausi* and *Oithona nana*, show evidently two trends,

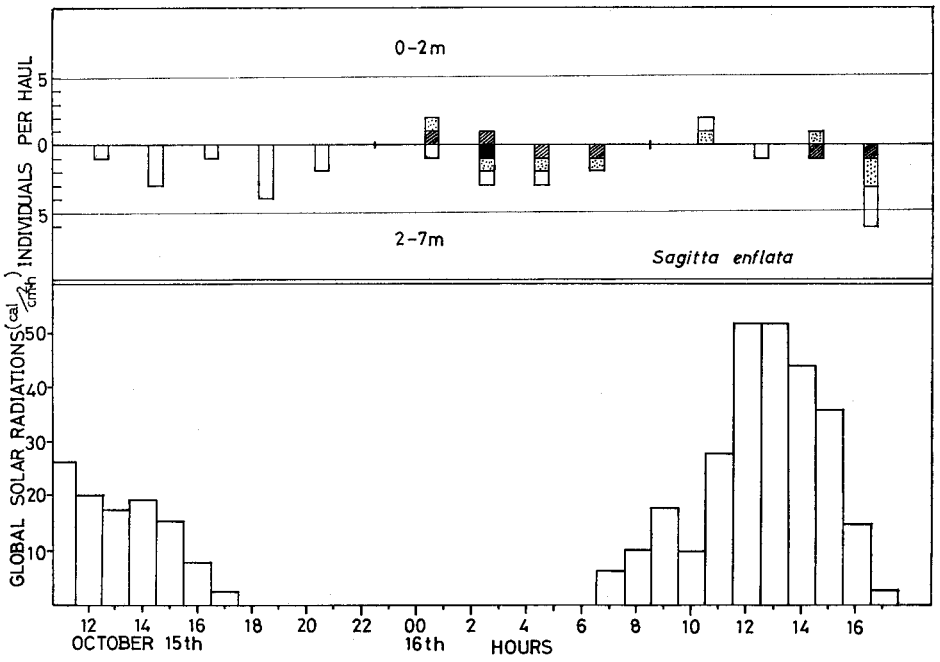

Fig. 11. Diel variations of the occurrence of *Sagitta enflata*, given separately in four maturation stages I to IV in 0–2 m and 2–7 m layers at Station A, and below the global solar radiation (cal./cm^2/hr) at the same station.

namely the diel vertical migration and its differentiation between male and female, especially clearly in *Acartia*.

Of course, the changes in the vertical distribution and differences seen in them between male and female cannot be attributed wholly to the diel vertical migration of these copepods. Water columns in the bay should be, at least partially, displaced at tides even in such bays on the Japan Sea coast, where the tides are extremely small; the horizontal circulation of the bay water, characteristic to Maizuru Bay, might carry different water masses to the stations; and the influx of the ocean water might sometime attain so deep into the bay around these stations as suggested on the 16th afternoon. Sudden drop of the water temperature and salinity and raise of the amount of phosphate phosphorus in the surface layer at the stations at the lowest water are probably showing the retreat of the surface sea water and advance of the fresh water through rivers in the area. Thus, the changes referred to above might reflect, to some extent, the differences of horizontal distributions of male and female in the bay water, that were brought about by different behaviours with age.

However, the changes occurred in the surface layer quite similarly as in the 2–7 m layer. Therefore, it may safely be concluded that the observed differences of the diel vertical migration between male and female are the general trends. Throughout the three copepods, *Paracalanus, Acartia* and *Oithona,* it is recognized that males do the diel vertical migration more actively than females. This conforms well to what was told by Motoda and Sato (1949) as to the open-sea copepods, *Pseudocalanus,*

Clausocalanus, *Tortanus* and *Centropages*.

LITERATURE

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